Maximizing Cotton Production and Rye Cover Crop Biomass through Timely In-Row Subsoiling

R. L. Raper, E. B. Schwab, J. S. Bergtold, A. J. Price,
K. S. Balkcom, F. J. Arriaga, T. S. Kornecki

Abstract. *Most tillage and fertilizer practices attempt to maximize cash crop yields and do not focus on increasing cover crop yields. This project was conducted to determine the optimum time to perform in-row subsoiling in order to maximize cash crop and cover crop production which is a common and necessary practice. Two implements (Paratill and a KMC Rip/Strip) were used to perform in-row subsoiling at 6-week intervals beginning in the late fall in a Coastal Plains soil. A rye cover crop was used to precede a cotton cash crop. Crop yields, soil strength, soil moisture, and infiltration were measured to assess differences in productivity and soil condition. Large amounts of variation were found in both production of cover and cash crop potentially due to erratic rainfall. Results indicated that maximum yields occurred for the cash crop and the cover crop by performing in-row subsoiling late in the spring after the cover crop had been terminated. All in-row subsoiling treatments were found to be superior to no-tillage which exhibited reduced plant growth, infiltration, and increased soil compaction.*

Keywords. *Tillage, In-row subsoiling, Soil compaction, Cover crops, Biomass.*

Soil compaction has been shown to reduce cotton (*Gossypium hirsutum* L.) crop yields in the southeastern United States (Camp and Lund, 1964; Carter et al., 1964; Lund, 1967; McConnell et al., 1989; Melville, 1976; Schwab et al., 2002; Raper, 2005b). In-row subsoiling is one of the most common methods used to remove compacted soil conditions (Saveson and Lund, 1958; Box and Langdale, 1984; Busscher and Sojka, 1987; Raper, 2005d). Subsoiling disrupts compacted soil profiles, improves infiltration, increases soil moisture storage, and allows roots to proliferate downward to obtain adequate soil moisture and potentially improve crop yield (Raper and Bergtold, 2007).

However, the shape of the subsoiler shank can have a large effect on the amount of soil disturbed both aboveground and belowground (Reeder et al., 1993; Raper, 2002; Raper, 2004; Raper, 2005a; Raper, 2005c). Increased belowground soil disruption coupled with reduced aboveground disruption have caused many producers to consider bentleg shanks as the preferred method of in-row subsoiling while maintaining conservation compliance (Harrison et al., 1991; Raper, 2005a).

Several studies have documented the benefits of in-row subsoiling on cotton production. In a two-year study, Touchton et al. (1986) found in-row subsoiling significantly improved cotton yields on a sandy loam soil but only improved yields for one year on a silt loam soil. Mullins et al. (1997) found a 22% improvement in cotton yield also on a sandy loam soil. In the Mississippi Delta on a clay soil, Smith (1995) found that subsoiling increased cotton yield by 15% in non-irrigated conditions. When irrigation was present, yield increases were only 8%. In another test on silt loam soils, Schwab et al. (2002) found that in-row subsoiling gave a 16% cotton yield improvement over conventional tillage and a 10% improvement over strict no-tillage.

The impact and timing of tillage practices on cover crop production has mostly been ignored in the quest to improve crop production. In-row subsoiling is often recommended to be performed when timing is most plentiful, in the spring prior to planting or in the fall after harvest. The impact of in-row subsoiling on cover crop production is not often considered. However, maximum environmental and productivity benefits have been associated with large amounts of cover crop biomass (Reeves, 1994). Improved weed control, increased infiltration, decreased evaporation, increased water storage, improved soil quality, and reduced soil compaction have all been found as benefits of cover crops. During periods of extreme drought, many producers have even allowed their cattle to graze cover crops as a food source.

The ability to quickly produce a biomass crop may even have future implications for bioenergy. As the United States develops the capability to develop liquid fuel from cellulose, one source of biomass that should not be overlooked is cover crops. Many producers in the southeastern United States should be able to grow large biomass cover crops that could exceed yields of 10-12 Mg/ha with the plentiful rainfall that

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The authors are **Randy L. Raper, ASABE Member Engineer,** Agricultural Engineer, Lead Scientist, **Eric B. Schwab,** Agronomist, USDA-ARS National Soil Dynamics Laboratory, Auburn, Alabama; **Jason B. Bergtold,** Agricultural Economist, Kansas State University, Manhattan, Kansas; **Andrew J. Price,** Weed Scientist, **Kipling S. Balkcom,** Research Agronomist, **Francisco J. Arriaga, ASABE Member,** Soil Scientist, and **Ted S. Kornecki, ASABE Member Engineer,** Agricultural Engineer, USDA-ARS National Soil Dynamics Laboratory, Auburn, Alabama. **Corresponding author:** Randy L. Raper, USDA-ARS National Soil Dynamics Laboratory, 411 S. Donahue Drive, Auburn, AL 36832; phone: 334-844-4654; fax: 334-887-8597; e-mail: Randy.raper@ ars.usda.gov.

is mostly available during winter months. However, adequate research must be conducted to ensure that soil quality does not degrade as a result of this potential bioenergy crop.

Therefore, an experiment was planned to determine if benefits in cash crop yields, cover crop yields, or soil properties could be improved through proper timing of in-row subsoiling. Specifically, the objectives of this study were:

- to compare two different in-row subsoiling implements (Paratill and KMC Rip/Strip in-row subsoilers), and
- to determine the optimum time of the year to conduct in-row subsoiling operations in order to maximize cash crop yield, cover crop yield, and improve soil properties.

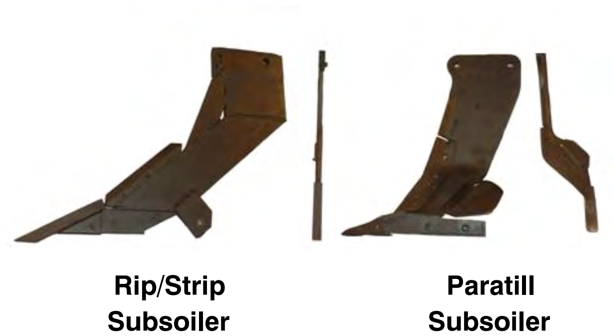

Figure 1. Side and front views of individual shanks used in the experiment.

Methods and Materials

This experiment was begun in the fall of 2004 at the E.V. Smith Research Center in Shorter, Alabama (south-central Alabama) on a Compass loamy sand soil (coarse-loamy, siliceous, subactive, thermic Plintic Paleudults) which is a Coastal Plain soil commonly found in the southeastern United States and along the Atlantic Coast of the United States. These soils are typically prone to subsoil compaction and usually require annual in-row subsoiling. This experiment focused on a continuous cotton production system which produced crops during 2005, 2006, and 2007. The research site was used for a rye cover cropping experiment the previous year and was kept fallow at the conclusion of the experiment. No deep tillage had been conducted on the site for several years.

Two implements were evaluated for this experiment (fig. 1). A Paratill, which is a bentleg subsoiler (Bigham Brothers, Lubbock, Tex.), was compared against a Rip/Strip in-row subsoiler (Kelley Manufacturing Company, Tifton, Ga.) with a straight standard angled with the horizontal at 45°. Tillage depth for the experiment was maintained at 41 cm for both implements. These implements are representative of a number of implements used for in-row subsoiling in the region.

The timing of in-row subsoiling was the major subject of the experiment and was varied from late fall until spring prior to planting. Four times were selected beginning in mid-December and then spaced approximately 6 weeks apart. These times were mid-December, late-January, early-March, and late-April.

The experimental design was a randomized complete block with a 2×4 factorial arrangement of treatments augmented with an additional control treatment of no-deep tillage. The two factors investigated were: 1) in-row subsoiling implement (Paratill or Rip/Strip) and 2) timing of in-row subsoiling (four times). Each treatment was replicated four times (36 plots).

The plots for the experiment were four, 100 cm rows wide (4 m) × 15 m long. After the cotton was harvested in the fall, a rye (*secale cereale*) cover crop was planted and grown throughout the winter months. During the cover crop growing period, the in-row subsoiling was conducted until the following spring when the cover crop was terminated by using glyphosate and rolling. Chemical termination is the normally recommended practice of cover crop termination and provides excellent results. Rolling is often practiced on high biomass cover crops as a method of flattening the crop and enhancing the ability of the planter to effectively seed a cash crop. Typically, growers are advised to wait at least two weeks between cover crop termination and planting of the cash crop to allow the cover crop to completely die and prevent competition for the same available soil moisture. Auburn University Extension recommendations were used to apply all fertilizers, herbicides, insecticides, and defoliants for the cash crops. The cover crops received no additional fertilizer. The center two rows of each plot were harvested and weighed to obtain seed cotton yield. Rye was sampled by randomly placing two 0.25-m square frames within the plots. The harvested rye from the plots was oven-dried at 55°C to remove moisture and weighed to determine dry matter. The two values per plot were then averaged. Table 1 shows the dates of cover crop planting as well as cash crop planting and harvesting. Significant rainfall accumulated during the months following planting was also recorded.

Soil strength was determined in spring and fall by use of cone index measurements (*ASAE Standards,* 2004a; *ASAE Standards,* 2004b) which were obtained with the Multiple-Probe Soil Measurement System (Raper et al., 1999). A 12.83-mm diameter base cone with a 9.53-mm diameter shaft was used to acquire the cone index measurements. These measurements were taken at three positions within each plot with all five-cone index measurements being equally spaced at a 0.25-m distance

Table 1. Dates of cover and cash crop planting and harvesting and accumulated rainfall during the experiment.

		2004-2005	Rainfall (cm)	2005-2006	Rainfall (cm)	2006-2007	Rainfall (cm)
Planted rye		11/3/04		11/4/05		11/1/06	
	Nov.-April		79.6		48.9		56.7
Planted cotton		5/11/05		4/24/06		5/18/07	
	May-Aug.		39.5		28.9		29.7
	June-July		27.6		11.1		20.2
Harvested cotton		9/21/05		9/5/06		10/17/07	

across the soil with the middle measurement being directly in the path of the shank. Force data was collected at 25 Hz and averaged to obtain average values of force for each probe at 5-cm depth increments.

Using the same frame of the Multiple-Probe Soil Measurement System (Raper et al., 1999), soil moisture and bulk density measurements were also obtained in 5.08-cm depth increments in fall after harvest during the last two years of the experiment. These measurements were taken at three locations in each plot with the results averaged to create an average value per depth per plot.

Water infiltration into the soil was measured with a double-ring infiltrometer (Reynolds et al., 2002). The double-ring infiltrometer used was 15 cm high, with inner- and outer-ring diameters of 14.5 and 32 cm, respectively. The infiltrometer was carefully inserted 4.5 cm into the soil surface to minimize disturbance. Infiltration was measured in three locations (in-row) on each plot. Each measurement was conducted until steady-state conditions were reached, typically 10 min.

Data were subjected to ANOVA using the Statistical Analysis System (Littell et al., 1996). Where year by treatment interactions occurred for response variables, data were analyzed and were presented by year. Preplanned single degree of freedom contrast and Fisher's protected LSD were used for mean comparisons. A significance level of $P < 0.1$ was established *a priori*.

Results and Discussion

Cover Crop Biomass

Overall, the production of rye biomass was reduced somewhat during the first year of the experiment as compared to the two latter years (fig. 2). One possible explanation for this variation could be found in the rainfall data (table 1) for the winter months while the cover crop was growing. During the first year of the experiment, significantly increased rainfall occurred during the month of March when the cover crop was actively growing. This increased rainfall coupled with reduced sun probably contributed to the reduced biomass yields found for 2004-2005.

Due to the significant variation found between years of the experiment, each year of cover crop biomass yield was examined separately. The amount of rye cover crop produced in spring of 2005 did not vary significantly ($p \le 0.12$) based on the implement used or the timing of in-row subsoiling conducted during the preceding winter months (fig. 2; left). The only significant contrast that was noted was that December in-row subsoiling was more advantageous than March in-row subsoiling ($p \le 0.07$; 2109 vs. 3138 kg/ha, respectively). A trend was also noted that smaller amounts of cover crop biomass were produced by the no-till system as compared to a majority of the in-row subsoiling treatments.

Cover crop biomass results from spring of 2006 gave a greater amount of statistical differences (fig. 2; center). The implements were again found to not be significantly different ($p \le 0.16$). The cover crop yield (4865 kg/ha) resulting from the last date of in-row subsoiling (April) was found to be statistically greater than March in-row subsoiling ($p \le 0.01$), January in-row subsoiling ($p \le 0.01$), or December in-row subsoiling ($p \le 0.03$). December in-row subsoiling was also

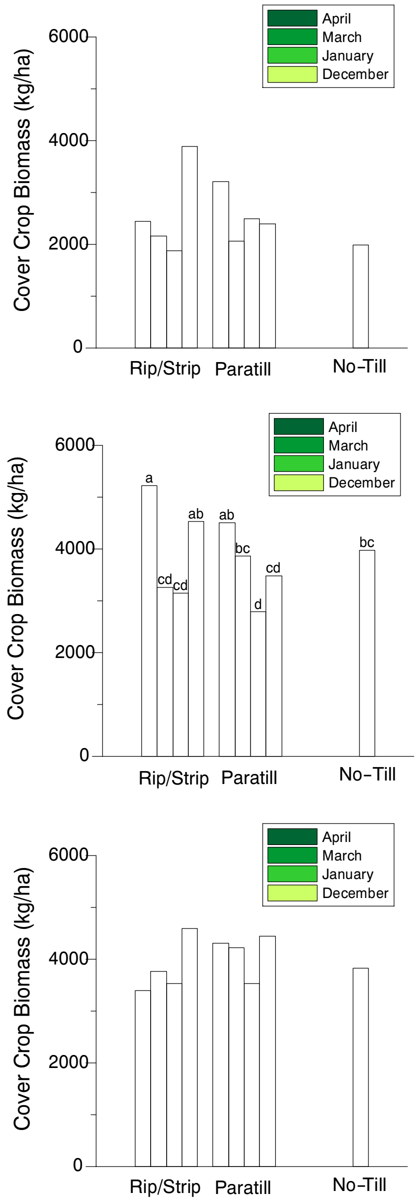

Figure 2. Rye cover crop biomass produced in 2004-2005 (left), 2005-2006 (center), and 2006-2007 (right). When present, letters indicate statistical significance ($LSD_{0.1}$).

found to be greater statistically than January in-row subsoiling ($p \le 0.01$).

Measurements of rye cover crop biomass taken in spring of 2007 again found no differences based on in-row subsoiling implement ($p \le 0.50$). The only statistically significant contrast that was identified was that December in-row subsoiling was found to be superior to January in-row subsoiling ($p \le 0.02$; 4518 and 3530 kg/ha, respectively).

Two points are noted when these data are examined. The first point was that decreased cover crop yields result when in-row subsoiling was not applied. Rye roots suffered from similar rooting restrictions as cash crop plants even though they grew during winter months when rainfall was more plentiful. The second point was that in-row subsoiling provided during the middle growth stages of rye (January and March) reduced maximum cover crop production. In-row subsoiling provided nearest the planting of the rye cover crop maximized production and was found to be superior to in-row subsoiling performed in January in 2 of the 3 years. Once the roots started to grow and proliferate, significant damage was done to the plants by performing in-row subsoiling. Waiting until the cover crop has been terminated (April in-row subsoiling) was also noted to produce good cover crop yields. It was interesting to note that the April timing of in-row subsoiling was actually the closest tillage operation prior to planting of the rye cover crop which occurred less than 6 months later.

Cash Crop Yield

There was no year by treatment interaction, so the data were pooled and analyzed. Seed cotton yield was found to be affected by tillage treatments averaged over timing (fig. 3, $p \leq 0.06$) with both the Rip/Strip (2765 kg/ha; $p \leq 0.01$) and the Paratill (2694 kg/ha; $p \leq 0.04$) being significantly greater than the no-till (2483 kg/ha). No significant differences existed between the Rip/Strip and the Paratill ($p \leq 0.27$). In-row subsoiling in April (2892 kg/ha; $p \leq 0.01$), March (2691 kg/ha; $p \leq 0.07$), or December (2682 kg/ha; $p \leq 0.08$) was found to be greater than no-till. Only January in-row subsoiling (2653 kg/ha) was found to be similar to the no-till treatment ($p \leq 0.13$). When only the timing of in-row subsoiling was considered, April was found to be superior to March ($p \leq 0.03$), January ($p \leq 0.01$), or December ($p \leq 0.02$).

The greatest seed cotton yields occurred with the timing of in-row subsoiling as close as possible to planting. In most years, longer periods of elapsed time between in-row subsoiling and planting caused seed cotton yields to be reduced. Also, the smallest seed cotton yields were found with no tillage which indicated that significant soil compaction existed that must be removed prior to planting.

Soil Strength and Soil Moisture

Soil moisture from 0- to 30-cm depths obtained at the time of tillage conducted from fall of 2006 to spring of 2007 showed no differences between tillage implements (fig. 4). However, differences were found between the timing of in-row subsoiling. The highest two values of moisture content occurred with timing of in-row subsoiling events that occurred earliest in the year (March and January). The lowest two values of moisture content occurred with the greatest elapsed time since occurrence of the previous in-row

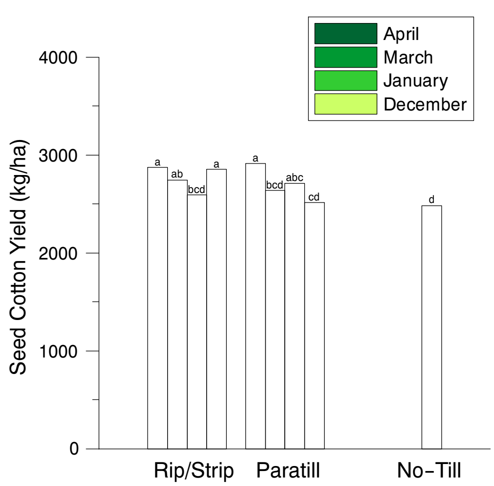

Figure 3. Average seed cotton yield produced in 2005-2007. When present, letters indicate statistical significance ($LSD_{0.1}$).

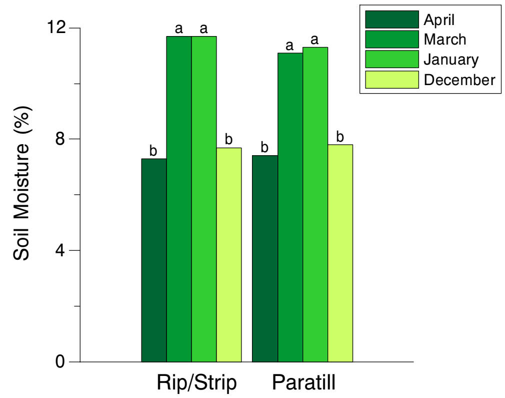

Figure 4. Gravimetric soil moisture content taken at the time of in-row subsoiling from fall of 2006 to spring of 2007. Letters indicate statistical significance ($LSD_{0.1}$).

subsoiling operations (December and the previous April). The drier soil moisture content values present at the times of December and April in-row subsoiling event probably contributed to additional disruption of the soil profile (Raper and Sharma, 2004) as compared to tillage conducted either in January or March. It is interesting to note that the increased production of the rye cover crop in 2007 associated with the December subsoiling event could have been assisted by the increased disruption of the soil profile caused by the drier soil moisture present at in-row subsoiling.

Cone index measurements (fig. 5) taken in the no-till plots in the spring of the last year of the experiment (2007) illustrate why in-row subsoiling was such a valuable production practice for the southeastern region of the United States. Root-limiting conditions were prevalent throughout the rooting zone with values of cone index exceeding 2 MPa, which caused root restrictions according to Taylor and Gardner (1963) occurring at depths of less than 10 cm. Also, note that in all graphs that the extremely high cone index values were found to the left of each graph in the trafficked row middle and occurred at approximate depths of 20 cm.

As the time elapsed since in-row subsoiling increased, note how the disturbed zones caused by the tillage event narrows slightly and moves toward the soil surface (fig. 5). This narrowing indicated how the soil was reconsolidating and returning to a more compacted state. As expected, the maximum amount of disturbance and minimum values of cone index were associated with the in-row subsoiling event most recently completed (April). Also, note that there was little difference between the two implements studied with the graphs created from data obtained with the Rip/Strip implement occurring on the left and the graphs from the Paratill occurring on the right.

Cone index data obtained in the fall of the year after harvest (fig. 6) showed that the compacted regions not disturbed by in-row subsoiling increased significantly in compaction as compared to those data from earlier in the spring. However, the cone index values obtained in those zones disturbed by the tillage event have not substantially increased.

As earlier hypothesized, some differences in infiltration were noted based on the elapsed time since the in-row subsoiling treatments had been performed (fig. 7). The major finding, however, was that all plots that had received an in-row subsoiling treatment had infiltration more than two

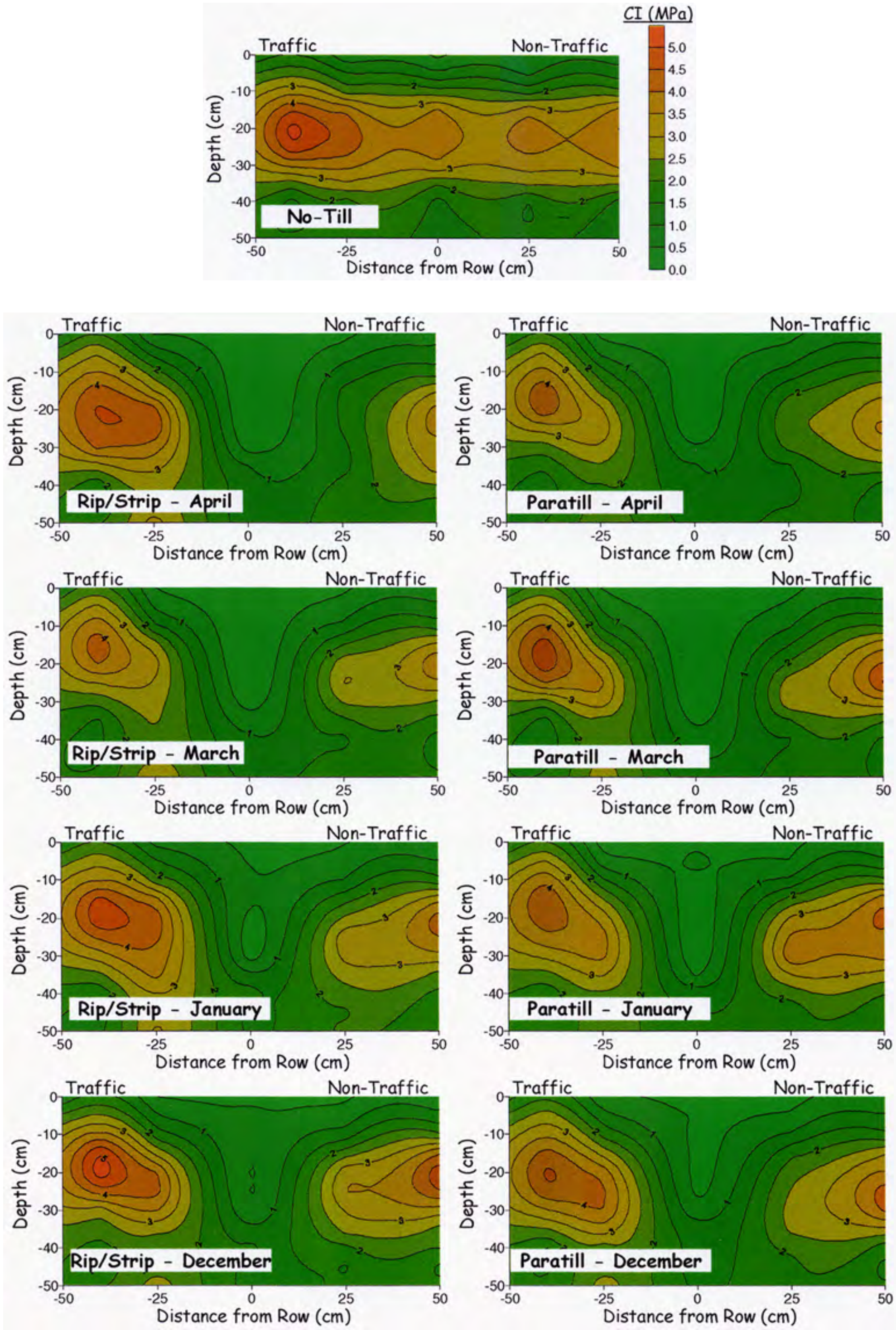

Figure 5. Iso-lines of cone index measurements taken in the spring of 2007.

times greater than that in the no-till treatment that had never received any in-row subsoiling treatment ($p \leq 0.01$). Increased soil compaction, reduced rooting, and reduced water holding capacity are all byproducts of reduced infiltration associated with the no-till treatments.

Soil bulk density measurements taken in the in-row position after harvest in 2007 (fig. 8) showed that the no-till plots had significantly increased soil compaction associated with them as compared to all of the other plots that had received some form of in-row subsoiling. Bulk density values in the plots that received in-row subsoiling with the Rip/Strip implement behaved as expected. From the soil surface down to the depth of in-row subsoiling, the lowest values of bulk density were found to coincide with the minimum time elapsed since the in-row subsoiling event. This pattern was not as easily seen in the Paratill plots, perhaps due to the bentleg nature of the implement and the maximum amount of disruption occurring slightly out of the in-row position.

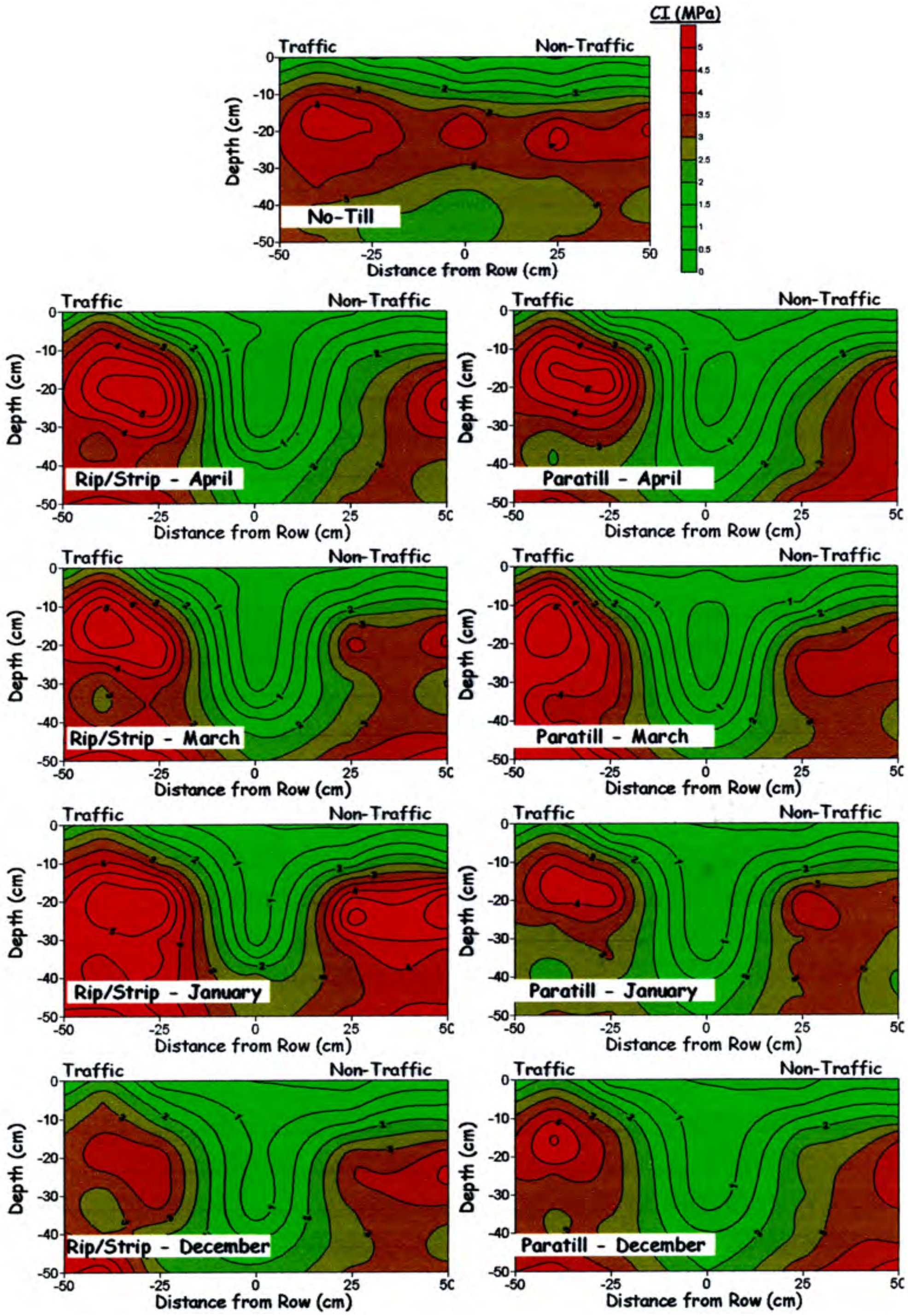

Figure 6. Iso-lines of cone index measurements taken in the fall of 2007.

Differences in soil moisture were noted throughout the entire soil profile with no-till typically having the greatest soil moisture near the surface, but quickly being reduced to significantly below all in-row subsoiling treatments at depths of 20 to 40 cm (fig. 9)

Conclusions

- Cover crop production was maximized by performing an in-row subsoiling operation either near the time of planting or after termination of the previous cover crop. Soil disruption performed during the winter months when the cover crop was dormant decreased cover crop biomass.
- Cash crop production was maximized by performing in-row subsoiling as close to planting as possible, with the April timing being the most suitable for Southern U.S. soils and climate.
- Infiltration, cone index, soil moisture, and soil bulk density were all found to be improved through in-row subsoiling. The timing of the operation was not critical to improve these properties.

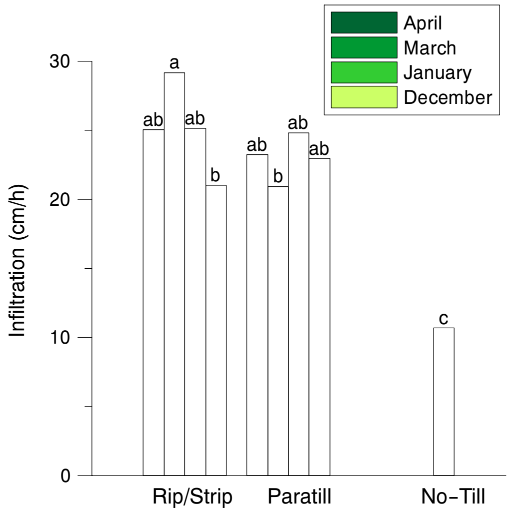

Figure 7. Infiltration measurements obtained in the fall of 2007 after harvest. Letters indicate statistical significance ($LSD_{0.1}$).

- No differences were noted between in-row subsoiling implements.
- The best time to perform in-row subsoiling should be based on maximum production of both the cash and cover crops. For soils and climate in the Southern U.S., similar maximum production levels of cover crops were found with either early winter in-row subsoiling or post cover crop termination in-row subsoiling. Maximum growth of the cash crop was mostly found with post cover crop termination timing. Our recommendation would therefore be to perform in-row subsoiling late in spring after cover crop termination in order to maximize performance of the cash crop without sacrificing cover crop yields.

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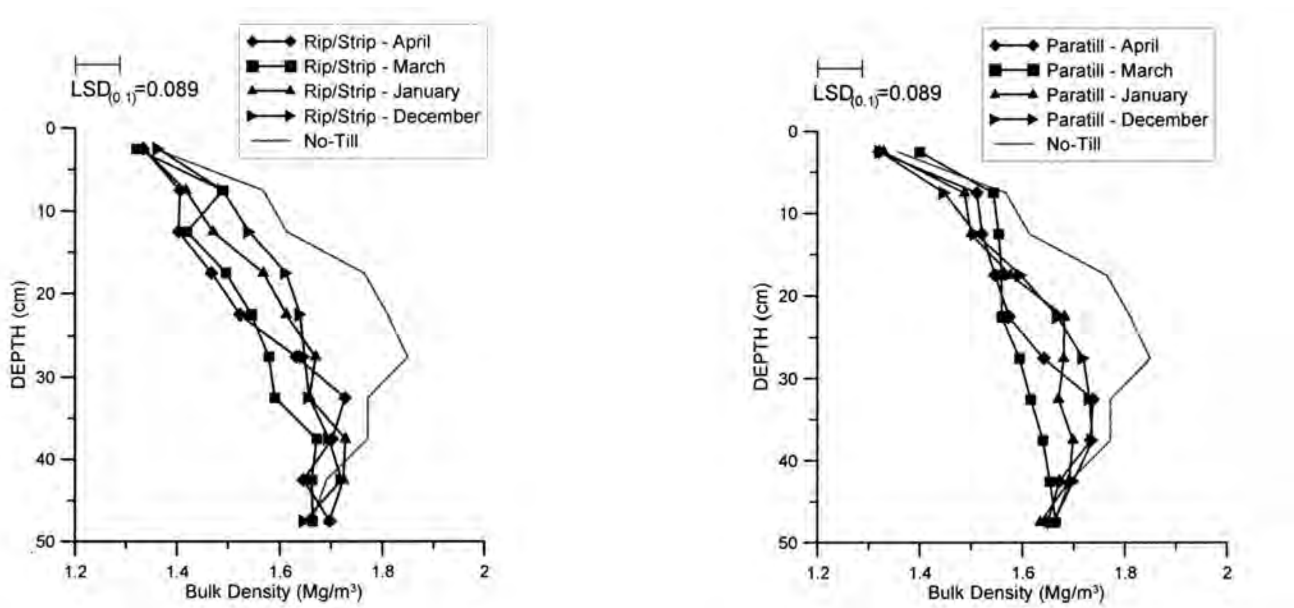

Figure 8. Bulk density measurements obtained in the fall of 2007 after harvest for the Rip/Strip in-row subsoiling implement (left) and the Paratill (right).

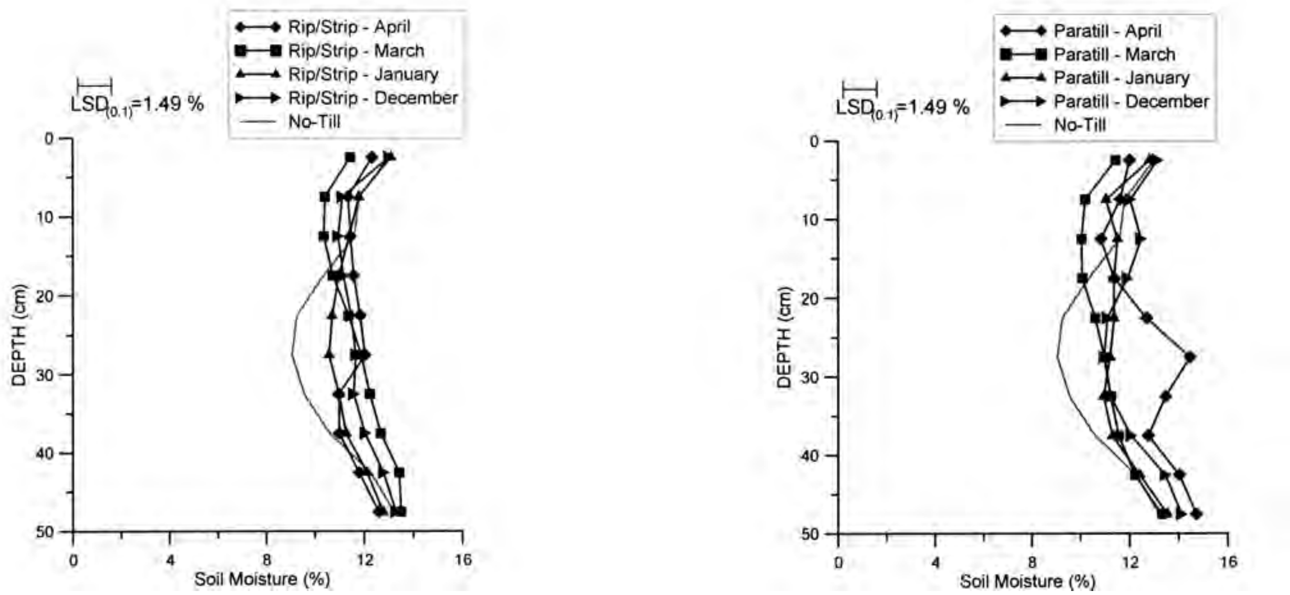

Figure 9. Soil moisture measurements obtained in the fall of 2007 after harvest for the Rip/Strip in-row subsoiling implement (left) and the Paratill (right).

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